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BLAST FURNACES. AN INDUSTRIAL WASTE GUIDE TO THE BLAST FURNACE DEPARTMENT OF THE STEEL INDUSTRY

ENVIRONMENTAL HEALTH CENTER, CINCINNATI, OHIO

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BLAST FURNACES

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FEDERAL SECURITY AGENCY
Public Health Service
Environmental Health Center
Cincinnati, Ohio

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AN INDUSTRIAL WASTE GUIDE TO THE BLAST FURNACE DEPARTMENT OF THE STEEL INDUSTRY

Abstract

A primary operation in the transformation of iron ore to steel is the production of pig iron in blast furnaces. During 1950, in the United States, 229 furnaces located at 86 establishments produced 64,586,907 net tons of pig iron. Ore, coke, and limestone are charged at frequent regular intervals to the vertical cylindrical chamber of the furnace and preheated air is blown in near the bottom. Combustion of the coke generates heat and produces gases. Carbon monoxide of the gases combines with and removes the oxygen of the ore. The mass of material moves toward the bottom of the furnace and as it reaches the hottest part, the materials become molten. The molten limestone combines with non-metallic matter of the ore, causing it to become fluid. The fluid materials gather in a pool at the bottom of the furnace. Iron separates in a layer on the bottom; other materials, termed slag, float on the molten iron. These materials are periodically drained from the furnace.

Enormous quantities of gases, consisting of combustion products of the furnace and non-reactive constituents of the air, are conducted from the furnace. The gases have fuel value and contain significant amounts of ore and coke dust. Dust is removed from the gas in order to reduce corrosion, to prevent difficulties in operations, and to recover the dust. The gases are cleaned to dust contents in the range of 0.002 to 0.1 grain per cubic foot. Approximately two thirds of the dust is removed

in the dry state in devices known as dustcatchers. The dust content is commonly further reduced by means of wet washers which consist of towers containing numerous water sprays and layers of material presenting extensive wetted surfaces. Dust contacting the drops or surfaces or upon which sufficient condensation occurs is removed in the washer. Further cleaning may be accomplished by means of electrical precipitators or by disintegrators. In an electrical precipitator the dust particles become charged as they pass between highly charged electrodes and are impelled to the grounded electrode. This electrode is kept clean by a continuous flow of a thin water film. Disintegrators provide means of obtaining intimate contact between the gases and water sprays.

Liquid wastes from these operations consist of the discharge from the washers and electric precipitators. The volume ranges from 1500 to 5000 gallons per ton of pig iron produced. Suspended solids, which is the principal pollutional feature, range from 600 to 3500 parts per million. These suspended solids contain 16 to 60 pounds of iron and 4 to 6 pounds of coke per ton of pig iron produced.

Dry cleaning of blast furnace gases in all stages eliminates wash water use and is therefore the most effective remedial measure. The type of bag filter originally employed for such cleaning required careful and complicated operation; however, a recent development is claimed to be capable of eliminating these disadvantages and has definite advantages over wet cleaning.

The remedial measure most generally employed is the removal of the more readily settleable material from the gas wash water in sedimentation tanks providing 40 to 120 minutes detention. The suspended solids of wastes so treated may range from 60 to 400 ppm. Coagulation and flocculation of the

wastes is practiced at one plant. This plant reuses the effluent. Material removed in the settling units is dewatered and sintered then recharged to the furnace; a definite economic gain has been demonstrated.

Operation of furnaces under top pressure, within certain limits of blast volume, reduces gas velocities in the furnace and consequently dust production. Oxygen has been reported used in blast furnaces on plant scale by two companies; gas velocities and dust production are reduced by such practice.

AN INDUSTRIAL WASTE GUIDE TO THE BLAST FURNACE DEPARTMENT OF THE STEEL INDUSTRY

The steel industry in the United States operated 229 blast furnaces in 1950. Production of pig iron and ferro-alloys for recent years was as follows:

Year	1940	1945	1948	1949	1950
Production, thousands of tons	47,399	54,919	61,912	54,917	64,587

These blast furnaces are located at 86 establishments in 18 states. More than fifty per cent of these establishments are in the states of Ohio and Pennsylvania.

Water use for washing of blast furnace gases is estimated at 500 million gallons per day. The principal pollutional feature of the process wastes is suspended solids which consist of fine particles of ore, coke, and limestone. The untreated gas wash wastes of one year's operation of all blast furnaces in this country are estimated to contain approximately 1,500,000 tons of suspended materials.

Manufacturing Process

The first of three distinct steps in the manufacture of steel is the production of pig iron from the ore in blast furnaces. This is followed by purification of the pig iron and adjustment of certain constituents in open-hearth furnaces, Bessemer converters, or electric furnaces. Finally the steel is shaped to the desired product by means of rolling mills. These three operations may be carried out at one

integrated plant or at separate locations. This guide is concerned with the liquid wastes of the blast furnace department only.

Pig Iron Production

The blast furnace is a vertical, quasicylindrical structure, about 65 to 106 feet high and 15 to 28 feet in diameter. In operation, it is maintained full of a mixture of ore, coke and limestone, and functions continuously for months at a time. The materials are admitted at the top of the furnace and a large volume of air, preheated to between 1000 and 1500° F. is blown in near the bottom. Combustion of the coke produces carbon monoxide which subsequently removes oxygen from the ore. Two charcoal burning furnaces are known to be in existence. The uncombined iron melts at the high temperature reached in the furnace, 2900-3600° F., and flows into a pool three or four feet deep at the bottom of the furnace. The limestone or other fluxing agent performs a purifying or purging job by rendering fluid, at furnace temperature, the rock and undesirable elements of the ore and the ash of the fuel. This material, termed "slag," over 90% of which is made up of oxides of calcium, silica, aluminum and magnesium, collects on the top of the iron pool at the bottom of the furnace.

The molten iron and slag are removed separately at regular intervals from the furnace by opening tap holes at appropriate levels. The pig iron is drained to a ladle and kept in a molten condition while delivering it to steel making operations or to a series of molds on a slowly moving endless chain. In the molds the iron solidifies into bars known as "pigs," which weigh usually from 50 to 100 pounds. These "pigs" may be stored or shipped for later charge to steel making furnaces or remelted and treated for making

castings. The daily production of blast furnaces ranges from a few hundred to 1750 tons of pig iron.

Gas Cleaning

Enormous amounts of gas are liberated within the blast furnace, which, together with the nonreactive constituents of the air, are conducted from the furnace through large pipes at the top. The gas is led to the dust-catcher for the mechanical separation of the major portion of the dust; thence it is conducted through primary and secondary cleaners and away for various heating purposes in the plant.

Blast furnace gas contains sufficient carbon monoxide to give it a fuel value of about 90 BTU per cubic foot. About one quarter of the gas is burned in stoves where the furnace air is preheated. The remainder is used for metallurgical heating, for generating steam, for driving air blowers, or for heating coke ovens.

The gas amounts to about 110,000 cubic feet per ton of pig iron produced (measured at standard conditions, 60°F and 30 inches of mercury) and carries with it fine particles of ore, coke, and some alkali. The particle diameters range from about one-tenth inch to two millionths of an inch. The dust content is commonly from 4 to 20 grains per cubic foot (5.6 grains per cubic foot normally corresponds to about 100 pounds of flue dust per ton of pig iron produced).

Separation of dust from the gas is necessary, to avoid fluxing of refractories, accumulation of deposits in gas-consuming equipment, and erosion of equipment. The degree of cleanliness necessary for various uses of the gas is not standardized. General practice is to clean blast furnace gases to dust contents of at least 0.1 grain per cubic foot to as

clean as 0.002 grain per cubic foot. Plants may clean to a high degree only that portion of the gas for certain uses. A portion of the dust remaining in the gas is transferred to the stacks of units burning the gas and, unless removed from the stacks by collectors, contributes to atmospheric pollution.

In addition to dust, the gases carry between 7 and 50 grains of water vapor per cubic foot. Gases leaving the furnace may be from slightly lower than 300°F to as high as 600° F; consequently, unless precautions are taken, cooling to the point of condensation is likely. Dust will accumulate in the condensate and restrict conduits. The reduction of moisture is likewise desirable for combustion efficiency.

Recovery of valuable materials from the dust is an additional incentive to cleaning. Iron in the dust can be recovered by recharging the dust to the furnace. The carbon of the dust contributes heat to the sintering process. A method for recovery of iodine and potassium chloride from blast furnace dusts was developed in Germany during wartime search for independent supplies (1).

Methods employed for separating dust from the gas are numerous. For a thorough discussion of principles of operation and description of blast-furnace gas cleaning plants the reader is referred to an article by Jennings (2). He suggests possible lines of improving separating power and mechanical efficiency and draws attention to the lack of data on this subject, particularly on water-spray systems and the behavior and nature of blast-furnace dust. In general, the operation consists of three stages, namely: dry dust separation in dustcatchers, primary cleaning in wet washers, and final cleaning by wet-type electrical precipitators or disintegrators. Primary dry cleaners may be employed in place of wet cleaners, and final

cleaners may by dry-type electric precipitators.

(a) Dustcatcher - The dustcatcher is commonly of the momentum type as illustrated in Figure 1. It is a vertical cylindrical shell, about 30 feet in diameter, which is fitted with an inverted conical bottom and a cone-shaped top. The gas enters the dustcatcher through a vertical pipe that extends into the lower portion of the catcher. In latest designs, the pipe is flared outward toward the bottom. The gas passes around the bottom of the pipe and up to an outlet near the top. The initial momentum of the dust particles as well as gravitational forces carry them to the bottom of the catcher from which they are continuously removed by a pug mill. These units remove from 40 to 85% of the dust. Leaving the dustcatcher, the gas contains between 0.5 and 5 grains of dust per cubic foot.

(b) Primary Wet Washers - Primary wet washers are cylindrical steel towers, with conical bottom and conical top, in which the gas is made to pass through water sprays or over extensive wet surfaces. The towers are ordinarily 11 to 20 feet in diameter by 40 to 70 feet high. Gas enters the tower at a point near the bottom and passes out near the top, moving counter to the falling water sprays. Figure 1 shows a typical washer. Primary washers include stationary-spray towers, revolving-spray towers, Feld washers, baffle towers, spray fans, and combinations of these types. The stationary-spray tower is most used. It contains three or more banks or layers of contacting media such as tile or wood. Above the layers are water sprays which cover the cross section of the washer with water drops. The layers of media split up the rising gas and tend to prevent channeling and the wetted surfaces present extensive surface area to the moving gases. It is claimed that spiral-shaped tile with parallel passages constitute the most effective contacting layers (3). Dust particles which

8 (a)

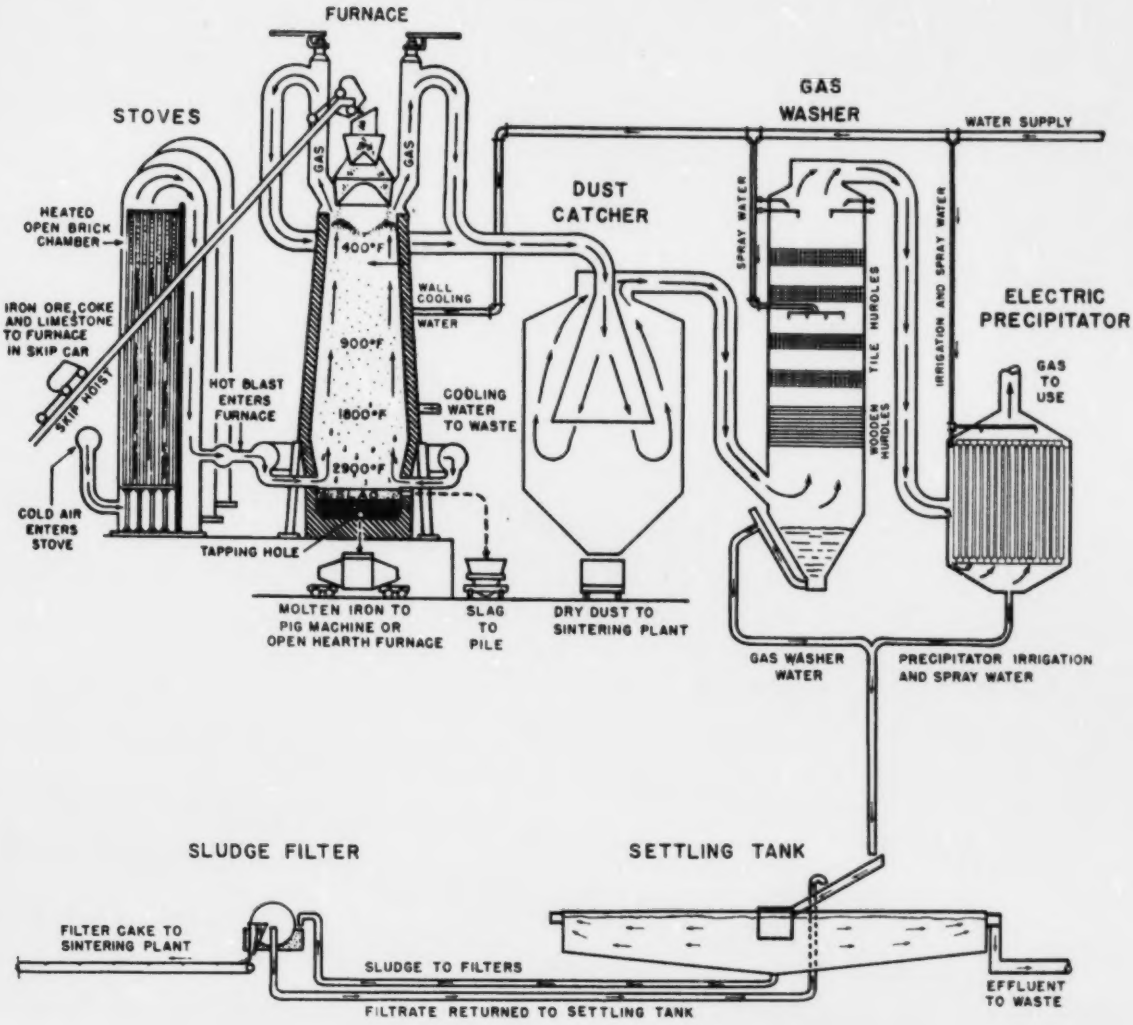

FIGURE 1

FLOW DIAGRAM
BLAST FURNACE OPERATIONS

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contact the water drops or the wetted surfaces are washed out of the tower with the spray water through a trapped outlet at the bottom. Cooling of the gases causes a condensation of moisture. This condensation is considered to take place in part on dust particles and thus aids in their removal.

Many Feld washers remain in use. Spaced uniformly along the axis of the tower of the Feld washer are 5 to 7 inverted frustums of cones which are rotated rapidly. They dip into a water tray from which they pick up water and spray it outward over the cross section of the tower. Baffles guide the water back into the tray for re-use, the excess water spilling into the next tray below.

There are numerous other wet washers; several different designs are presented in Figure 2. All are designed to employ some of the following principles:

(1) Subdivision of the gas into small streams

(2) Turbulence of flow of gas streams

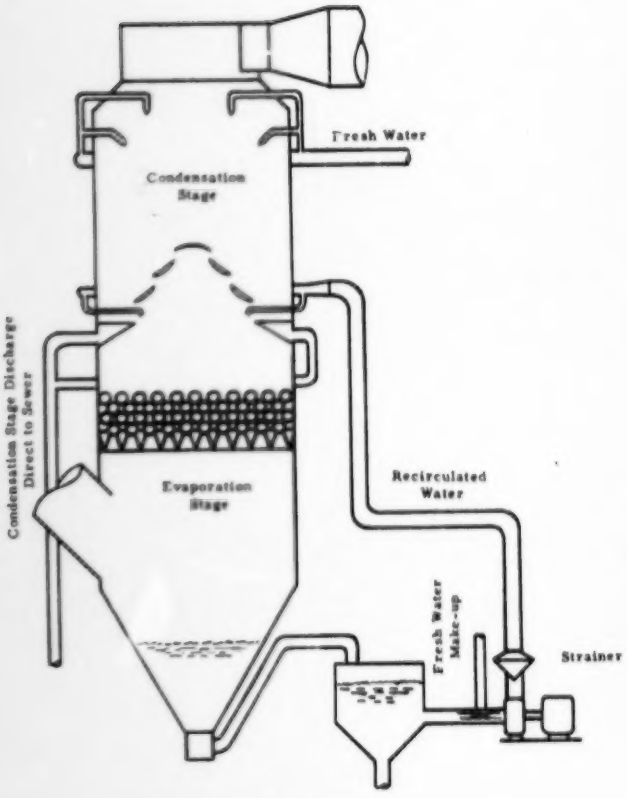
(3) Contact of gas with numerous water drops and extended wetted areas, and

(4) Wetting by water vapor condensation

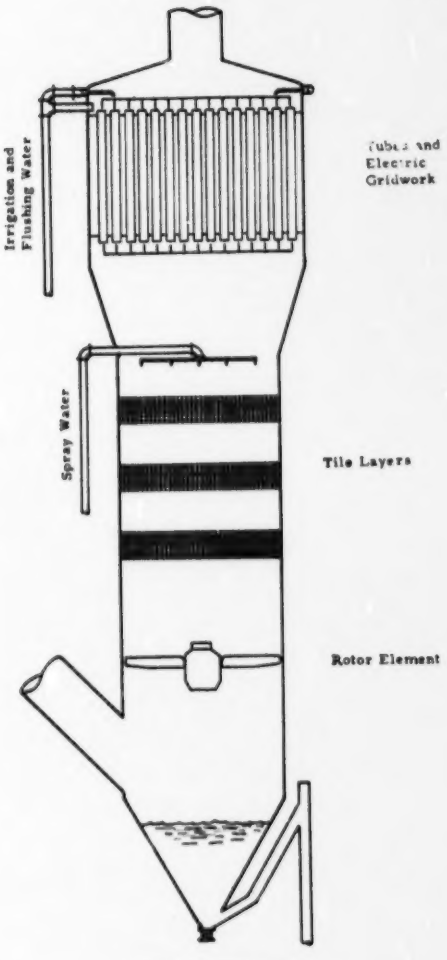
Gas leaving primary wet washers usually contains 0.05 to 1.0 grain of dust per cubic foot.

(c) Final Cleaners, Wet Type - Final cleaning is accomplished by any one of the following: electrical precipitators, high-speed disintegrators, Theisen disintegrators, and stationary disintegrators.

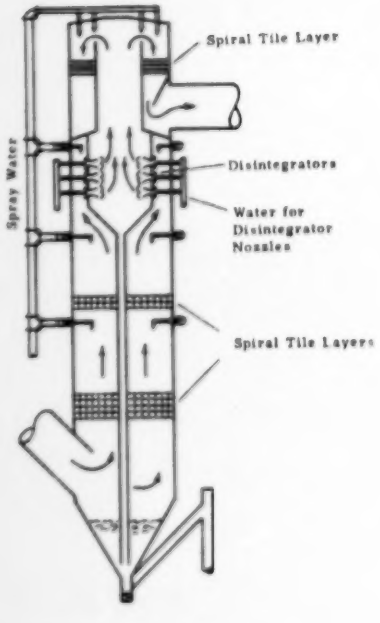
In precipitators, the primary cleaned gas is forced to pass through narrow channels or ducts across which a high-tension electric field is maintained. A potential of unidirectional current of from 30,000 to 80,000 volts causes a corona discharge from one electrode which produces a large number of positive gas ions. The gas ions attach themselves to the dust particles which in turn



WET WASHER WITH RECIRCULATION



WET WASHER WITH ELECTROSTATIC PRECIPITATOR LOCATED ON TOP



COMBINED WET WASHER–STATIONARY DISINTEGRATOR UNIT

SCALE
Approximate for All Figures

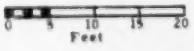


FIGURE 2

PRIMARY GAS WASHERS

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become charged. Unlike electrostatic charges attract; therefore, the dust particles travel to the negative or grounded electrode. In most precipitators, the collecting electrode is a vertical tube 8" or 12" in diameter or it may be of parallel steel plates through which the gas is forced upward or sideways. The charged electrodes are rods placed midway between the plates or in the center of the tubes.

The dust reaching the collecting electrode, tube or plate, is caught and carried away by a thin film of water continuously flowing over the surfaces. Water is introduced at the top of the tube or plates, so that it overflows evenly down the inside of the tube or faces of the plate. At intervals of one to twelve hours, additional water is sprayed into the precipitator for a few minutes to provide a heavy flush. In recent installations, the precipitator has been superimposed on the wash tower in order to economize space.

The Theissen disintegrator is a multibladed fan that intimately mixes water, introduced through small jets, with the gas which is forced through the device in opposite direction to the water. The rotary disintegrator is somewhat similar, but is smaller and revolves more rapidly. This disintegrator consists of a squirrel cage rotor mounted in a casing. Vanes mounted on the heads of the cage reduce the pressure-drop through the machine and force the incoming gas through the rotating bars of the cage upon which water is sprayed. The rapidly revolving cage gives the gas and water an intensive mixing as they flow through the spaces.

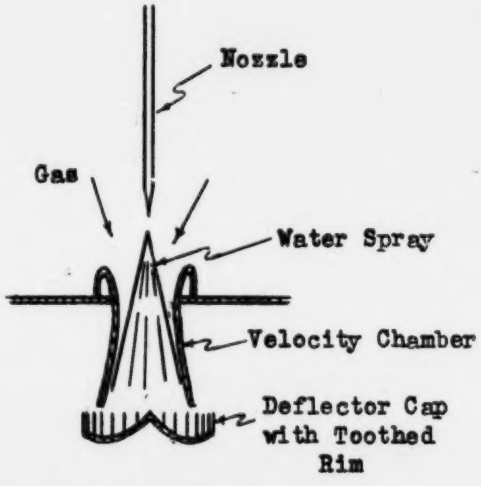

Figure 3. Stationary Disintegrator

The stationary disintegrator consists of a Venturi-shaped tube with throat about 4" in diameter in which is placed a high-pressure water nozzle that delivers a stream of finely divided water into the throat of the Venturi, Figure 3. The gas enters on all sides of the water nozzle; the mixture of gas and water then impinges on a dish-shaped baffle.

Gas cleaned by the final methods described may be expected to have a dust content between 0.002 and 0.02 grains per cubic foot. Moisture of the gas is reduced by the washing phases of gas cleaning from its original range of 7 to 50 grains per cubic foot down to 1 to 15. The temperature is likewise reduced from the initial temperature of 300 to 600° F to temperatures between 55 and 95° F.

(d) Primary Dry Cleaners - Primary dry cleaners include cyclone separators, centrifugal machines, and metallic-wool-pad filters. Cyclone separators are used abroad in place of dust catchers in some plants, and both here and abroad, as supplemental cleaners following the dust catcher. The cyclone separator is a cylindrical tank with a conical bottom. The gas enters the tank tangentially near its top. Centrifugal action plus gravitational forces cause dust particles to be thrown to the sides of the tank and to settle to the bottom. Centrifugal machines and metallic-wool-pad filters have been tried for cleaning following the dustcatcher, but have not met with wide adoption.

(e) Secondary Dry Cleaners - These cleaners have included bag filters and dry-type Cottrell precipitators. The bag type, sometimes called the Halberger-Beth filter, consists of a number of fabric "socks" into which the gas passes from the outside, forming a film of dust on the sock which acts as the filtering medium. When the film of dust becomes too thick, the exit end of the sock is closed, thereby shutting off the gas flow and the sock is shaken or vibrated

to drop the excess dust into a collecting hopper. The socks are stiffened and supported both circumferentially and longitudinally to prevent their collapse. One difficulty in these units has been the breakdown of the fabric in the high temperatures encountered with hot blast furnace gas. Also if condensation occurs, wetted dust deposits on the sock cannot be easily dislodged and may quickly stop gas flow. A recent development, tested on pilot plant scale, employing filters made of asbestos and glass fiber and a new design for mounting the bags, is claimed to overcome the difficulties (4).

The dry-type electrical precipitator operates on the same principle as the wet type but differs in construction. The collecting electrodes are slabs of reinforced concrete. Periodically, each unit is taken out of service to permit the dust on the collecting electrode to fall into a hopper below. In this type, the dust is detached from the collecting electrode by suspended chains which are used as scrapers.

Top Pressure Operation

At times of high demand, most furnaces are blown as rapidly as possible consistent with a reasonable loss of flue dust and with efficiency and regularity of operation. One of the limiting factors which govern rate of iron production of a furnace is the quantity of dust carried out in the gas. The tendency of the gases to carry dust, provided other factors are constant, is determined by the velocity of the gas. A relatively recent development has been the restriction of gas outlets in order to create pressure in the blast furnace. This results in reduced velocities of gases when comparing similar masses. An increase in the average static pressure of gas in a blast furnace decreases the volume and increases the density of the gas. This

permits a greater mass of air to be blown at decreased velocities through the furnace and consequently more pig iron can be produced. It follows that at any particular top pressure it would be possible to increase the volume of air blast to the point where critical velocities regarding flue dust would prevail just as in normal pressure operation. For example, computations show that identical velocities of air through a furnace would prevail when operating at ordinary pressure and using 85,000 cfm of air and when operating at 10 psi top pressure while using 120,000 cfm of air, both measured at normal temperature and pressure. Thus this top pressure permits an increase of over 40% in the mass of air in the blast with no increase in velocity. Any intermediate blast rate when using top pressure will result in reduced velocities and reduced dust concentration in the gas.

Raw Materials and Products

Raw Materials

Principal raw materials for the production of one ton of pig iron are approximately as follows:

Iron Ore	3600 pounds
Coke	1900 pounds
Limestone	900 pounds
Water	9000 gallons
Air	7000 pounds or [redacted]

Products

The product of the blast furnace is pig iron. It contains impurities such as carbon, sulphur, silicon and manganese which make it brittle and consequently of little use other than as a raw material convertible to steel or castings by further operations.

Blast furnace slag is used for several purposes. Slag processing plants operating in the United States process over 20 million tons annually. Most of the product is used for railroad ballast, cement, concrete aggregate, highway construction, and land-fill material. A substantial tonnage is used to manufacture mineral wool and a small amount is used in fertilizers for its high phosphorus content.

Hot slag may be used to evaporate pickle liquor. A method has recently been developed in which pickle liquor is neutralized with granulated slag.

Blast furnace gas, although of low BTU content, is of value particularly for use in the steel plant.

Volumes and Character of Wastes

Blast Furnace Gas Wash Water

(a) Combined Wastes. Combined wastes are those originating in the gas washers and electrical precipitators. Water is used in the washers for directly removing dust particles from the gas and in precipitators for washing dust from collecting electrodes as previously described in the section on manufacturing process. Data obtained from sampling and analysis of this waste at three plants are presented in Table 1 (5). The data presented in this table are for the waste prior to any treatment. The concentrations and quantities, except where noted, are net figures; that is, deductions for materials in the water

supplies have been made.

The concentrations of dust in the water are dependent upon the dust contained in the gases, the efficiency of the washer, and on the volume of water used. The more effective the dry dust catcher, the less dust there will be for removal by the washer and the more effective the washer the less dust for removal by the precipitators. These plants all employed dry dust catchers, gas washers of the scrubbing tower or the spray tower type, and electrical precipitators of the tube type. These units differed considerably in details of construction at the various plants and even at the same plant. Special features influencing dust production are noted in the table. As noted, one furnace was operating with lower than normal gas velocities in the furnace and the gas cleaning plant, accomplished by maintaining pressure in the top of the furnace. Plant Number 1, which utilized fine ore, operated a sintering plant for all fine ore, dust, and mill scale of the charge.

TABLE 1
BLAST FURNACE GAS WASH WATER
POLLUTIONAL CONSTITUENTS AND VOLUME
PER TON OF PIG IRON PRODUCED

Plant No.	Special Feature of Plant	Flow Gallons	Total Suspended Solids Pounds	Volatile Suspended Solids Pounds	Iron as Fe Pounds	Cyanides as CN Pounds	Phenols Pounds
1	Sintering	4730	26	3.9	17	0.050	0.028
2a	Top Pressure	3250	46	5.1	16	0.021	0.0008
2b	None	2280	63	6.1	22	0.013	0.0013
3	None	3300	42	5.2	16		

TABLE 2
BLAST FURNACE GAS WASH
WATER CHARACTERISTICS

Plant No.	Special Feature of Plant	Total Solids ppm	Dissolved Solids Total ppm	Suspended Solids		Iron as Fe ppm	Cyanide as CN ppm	Phenols ppm
				Total ppm	Volatile ppm			
1	Sintering	686	16	670	100	440	1.28	0.72
2a	Top Pressure	1850	140	1710	188	600	0.79	0.03
2b	None	3470	140	3330	319	1180	0.66	0.07
3	None	1920	380	1540	191	575		

Plant No.	Special Feature of Plant	pH Range of Composite Samples	Alkalinity Methyl Orange as $CaCO_3$	
			Water Supply ppm	Gas Wash Water ppm
1	Sintering	7.4 - 7.9	215	290
2a	Top Pressure	7.3 - 8.6	45	141
2b	None	7.5 - 9.4	45	147
3	None	7.1 - 9.4		

These results show that a considerable amount of the suspended material in the wastes is iron. Iron in solution is insignificant. Volatile suspended solids are considered to consist essentially of coke dust, although the presence of alkaline compounds is recognized as a source of error in this determination. The wastes contain a small amount of cyanide which is created in the furnace. A small amount of phenolic compounds are also present. The coke used in plant Number 1 was quenched with coke plant wastes containing considerable phenols. It is probable that some phenol remained with the quenched coke and was driven off in the blast furnace. The increase in alkalinity and pH is attributed to contact with the carbon dioxide and products of the limestone of the charge. Dissolved solids are increased a minor amount, probably in the form of calcium and magnesium compounds having their origin in the limestone.

(b) Separate Wastes - Gas wash water as previously discussed is the combination of waters from the washers and from the precipitators. With certain exceptions, these wastes are produced separately and need not necessarily be handled together. The exceptions occur when precipitators or stationary disintegrators are superimposed on wash towers, in which cases the two wastes are mixed. These wastes are usually combined for treatment for removal of settleable material but some mills treat the water from the washer alone. The characteristics and volumes of those separate waste waters are therefore of interest; such information is presented in Table 3.

Table 3

VOLUME AND CHARACTERISTICS OF PRIMARY GAS WASHER DISCHARGE AND OF PRECIPITATOR DISCHARGE

Plant No.	Flow Per Ton of Pig Iron, Gallons	Total Suspended Solids		Volatile Suspended Solids		Iron as Fe	
		ppm	Per Ton of Pig Iron Pounds	ppm	Per Ton of Pig Iron Pounds	ppm	Per Ton of Pig Iron Pounds
Primary Gas Washer Discharge							
1	3940	780	25.7	116	3.8	520	17
Precipitator Discharge							
1	790	67	0.4	9	0.06	14	0.09

Table 3 shows that the precipitator wastes make up about 17 per cent of the combined flow of the two wastes but contain only 1.5 per cent of the suspended solids. The precipitator waste is of more importance than indicated by this comparison because it contains a more significant portion of the extremely fine particles which are the most difficult to remove by sedimentation and most likely to remain in the waste after treatment.

(c) Comparison of Wastes from Various Type Washers - Considerable variation in the volume of water used for gas washing, per ton of product basis, occurs depending, among other factors, on the type of washer employed. Even among washers at the same plant and of the same construction the use of wash water per ton of pig iron produced ranged from 2250 to 4300 gallons. These washers utilized sprays and mechanical mixing with no contacting layers. The quantity of suspended solids removed by these washers was less variable, ranging from 34

to 50 pounds per ton of product. A fifth washer at the same plant contained layers of tile grids presenting extensive contacting surfaces; this washer used only 1500 gallons of water per ton of pig iron produced. It removed comparable amounts of suspended solids, 39 pounds per ton of pig iron produced. At another plant, towers with similar contacting layers used over 3900 gallons per ton of pig iron produced. Water consumption figures generally reported in the literature and found in the surveys for the various types of washing equipment are as follows:

Unit	Water Consumption Per Ton of Pig Iron Produced, Gallons
Primary Washing Towers	800 - 4300
Secondary Washers	
Disintegrators, Rotary	1100 - 1700
Disintegrators, Stationary	1200 - 1300
Electric Precipitators	220 - 1100

One outstanding fact reported was that the dust content in the gas coming from any furnace varies considerably from time to time, and that such variance has a great bearing on the efficiency of the gas cleaning operations (6). Slips in the furnace cause high dust production. Slips result from bridging of the stock in the furnace. When the wedged stock falls the explosion like release of gas carries abnormal quantities of dust from the furnace.

Furnace Cooling Water

The walls of modern blast furnaces are cooled by means of water passing through enclosed conduits known as cooling plates which are laid in the brick work of the wall. These coolers usually are employed only in the lower sections of the furnace where the temperatures are higher. At times when refrac-

tory linings are worn away to the point where the outside of the furnace wall becomes excessively hot, external sprays of water on the furnace wall may be employed. Cooling water volumes vary from 4000 to 8500 gallons per ton of pig iron produced. No material is added to this water in its use for cooling purposes. Temperature increases for the volume ordinarily employed are slight, ranging from 10 to 20° F.

Miscellaneous Wastes

One minor discharge originates from an emergency overflow in the side of the gas washer which is for the purpose of permitting water to overflow in case the drain from the bottom of the washer becomes plugged. A continuous flow of water is provided in order to maintain the seal and thus prevent the escape of a quantity of gas in case the water is blown out by excess gas pressure. This water amounts to about 25 gallons per minute per washer and passes through in an unpolluted condition.

Another miscellaneous waste is engine room floor washings and waste lubrication oils from blowing engines. At some plants, which burn coal as auxiliary fuel, ashes may be removed by a stream of water which sluices them to the sewer.

Pollutional Effect

The most objectionable feature of liquid waste from blast furnace gas washing operations is suspended solids. Some of the suspended material settles readily and thus forms a continuously renewed coating of inorganic material on the bottom of the lake or river. Such deposits are destructive to bottom organisms which constitute an important source of fish food. A large part of the suspended solids are ore and coke particles which impart

to the waste a deep gray to black appearance. The apparent color and turbidity persists even after removal of readily settleable material by the usual settling practice. Such apparent color and turbidity will be found objectionable from aesthetic considerations and for recreational uses of the water. It may constitute an added burden for subsequent treatment of the water for public or industrial use.

The waste may contain slight concentrations of phenols and cyanides. Phenols in quantities of 0.002 to 0.005 ppm in the presence of chlorine will produce chlorophenol (medicinal) tastes and odors in water. A concentration of 0.1 ppm of phenol alone imparts to water the characteristic taste and odor of phenol. Phenol in higher concentrations is toxic to fish. Cyanides are toxic to aquatic life, interfere with normal biological processes of natural purification in streams, present a hazard to agricultural uses of water, and are a menace to public water supplies and bathing. Cyanide has been reported lethal to fish in concentrations of 0.05 to 0.1 ppm as CN.

Calcium and magnesium compounds in solution in the wastes increase the hardness of the water and thus detract from its quality for subsequent uses.

Remedial Measures

The applicability and accomplishments of certain remedial measures have been established by their wide use; others are yet to be proven on plant scale. The measures include plain sedimentation, coagulation, dry cleaning, and operation at reduced gas velocities achieved by top pressure or use of oxygen.

Waste Treatment

(a) Plain Sedimentation - At the present time the treatment of wastes from blast furnace gas washing is almost entirely limited to plain sedimentation. Such treatment is practiced at most steel mills today. Material removed by sedimentation is composed, to a large extent, of iron ore and to a lesser degree of coke. Both of these materials are valuable. The fine ore can be sintered to larger size particles and recharged to the furnace. Combustion of the coke in the sintering process will provide heat for sintering.

Sedimentation units employed are of both circular and rectangular design. Modern basins are equipped with sludge collecting mechanisms. The more crude type of basin is divided into two units and has no sludge collecting mechanism. Intermittently one unit only is used while sludge is removed by crane from the other unit.

Data on clarification accomplished at two plants studied by the Environmental Health Center are contained in Table 4. The treatment units at both plants were circular tanks. At plant 1, the tank was 110 feet in diameter and water depth at the sides was 10 feet. At plant 2 the tank was 60 feet in diameter and water depth at the sides was 8 feet.

TABLE 4 - TREATMENT OF GAS WASH WATER BY PLAIN SEDIMENTATION

Plant No.	Theoretical Detention Period, Minutes	Suspended Solids		
		Influent ppm	Effluent ppm	Per Cent Suspended Solids Removal
1	120	660	64	90
2	45	1910	400	78

Plant No.	Iron as Fe			
	Influent ppm	Effluent ppm	Recovered	
			ppm	Per Ton of Pig Iron, Pounds
1	397	45	352	13.8
2	676	161	515	12.1

Plant No.	Volatile Suspended Solids (Coke)			
	Influent ppm	Effluent ppm	Recovered	
			ppm	Per Ton of Pig Iron, pounds
1	101	12	89	3.5
2	180	54	126	3.0

Sedimentation units of the type employed may be rated in terms of overflow rate in gallons per square foot per day. This follows from theoretical consideration of the mode of action of settling tanks. Ideally all particles will be removed whose settling velocities are sufficient to carry the particles from their initial position on entering the tank to the bottom of the tank during the period the water is retained in the tank. This is expressed in the following equation:

Time for particle 100% of which will be removed to settle through depth of tank = Theoretical detention time of water in tank

$$= \frac{D}{V_c} = \frac{AD}{Q} \qquad \text{or} \qquad V_c = \frac{Q}{A}$$

Where D = depth of tank
A = surface area of tank
Q = flow
V_c = critical settling velocity

The critical settling velocity or settling velocity of the particle which will settle through the entire depth of the tank during the detention time is directly related to the efficiency of the tank. Thus the ratio Q/A may be used as a criterion for comparing settling tanks. This ratio is usually expressed as gallons per square foot per day. The data of the preceding table are presented in this manner in the tabulation below. Data presented by Ess (7) relating the capacity of settling units to degree of clarification are also included.

Plant No. or Information Source	Theoretical Detention Period Minutes	Q/A Gallons per Square Foot Per Day	Suspended Solids Remaining in Effluent: Primary Wash Water and Secondary Cleaner Water ppm	Suspended Solids Remaining in Effluent: Primary Wash Water Only ppm
1	120	735	64	
2	45	1710	402	
Given by Ess (7)		400	80	
		600	160	50
		800	250	130
		1000	370	210
		1200	500	310
		1400		430

It is apparent that reduction in the volume of gas wash wastes will accomplish corresponding reductions in the size of sedimentation units or increase the effectiveness of existing units. Therefore gas washing systems which use the minimum amount of water in reducing the dust content to the desired level are desirable from this point of view.

Solids removed in the sedimentation unit are pumped out or removed pneumatically to a filter for further dewatering. The sludge contains from 25 to 50 per cent solids. The slurry withdrawn from the tank may be recirculated to obtain higher concentrations sufficient for optimum filtration or a second settling period may be provided for the slurry in order to reduce its moisture content before filtration.

Filtration of the sludge is necessary in order to reduce the moisture content to that suitable for sintering. Two types of filters are in general use; the cylindrical or drum type consists of a cylindrical framework over

which canvas is stretched. The disc type consists of a series of wheel-like frames mounted on a common axle and over which canvas is stretched. The lower portion of the drum or disc is submerged in a vat of slurry. A partial vacuum is applied to the submerged part thereby drawing the liquid through the canvas while the solids are retained on the canvas. The drum or disc revolves slowly, lifting the layer of solids from the slurry as it rotates. At another point in their rotation a slight pressure is applied to a segment of the inside of the canvas and the cake drops off to a collecting chute. The filtrate should be returned to the sedimentation tank influent and the filter cake, containing about 25 per cent moisture is transported to the sintering machine.

The composition of the sludge varies with the size of particle. Larger particles contain a minimum of about 35 per cent iron; the smaller particles contain less than 10 per cent. The solids of the sludge obtained at three plants investigated by the Environmental Health Center averaged from 32 to 66 per cent iron (5). The dust contains between 5 and 15 per cent carbon, which has significant heating value. It has been estimated that flue dust containing 15 per cent carbonaceous matter has sufficient fuel value to sinter over three times its own weight of additional fine ore.

Sintering was originally undertaken to dispose of dust, but today it is used extensively to agglomerate fine ore. The annual capacity of sintering plants in the United States in 1948 was 18,000,000 gross tons. The flue dust, filter cake, fine ores, and mill scale are mixed with suitable amounts of fine coke and placed in a dampened condition on a travelling grate. The coke is ignited by gas; then as it moves along on the grate is burned by a strong down draft of air. Incipient fusion agglomerates the fine material into particles of such size and strength that they may be satisfactorily charged to the blast

furnace.

The value of material recovered from settling of gas wash waters has been such as to repay the cost of the necessary sedimentation and filtering units within two years or less. A substantial economic gain is realized.

The overflow of the sedimentation units and the sludge slurry is stated to have a tendency to form deposits of scale on pipes conducting them.

(b) Coagulation - Treatment by sedimentation removes considerable of the suspended material but the wastes remain highly turbid. One plant, which practices recirculation of the gas wash waters, treats the waters by coagulation and sedimentation after it has passed several times through the system. Alum is used as the coagulant. Practically all suspended material can be removed by coagulation and sedimentation. The use of ferric and ferrous sulphate as coagulants for this purpose has been suggested (8). An abundance of ferrous sulphate is available at all steel mills employing sulfuric acid pickling. Most blast furnaces are part of integrated steel plants having such pickling operations in the rolling mill division. Sufficient alkalinity is probably present from the alkali content of the dust to react with the ferrous or ferric compounds to produce a floc. There even may be a sufficient reaction between ferrous iron and oxygen contained in the gas wash water to oxidize the iron to ferric state and form a floc. In fact, the disposal of waste pickle liquor to sewers or streams where the dilution water contained dissolved oxygen has been observed to produce flocculation. Coagulation promises a disposal system which would yield a high quality of waste from the gas washing operation, recover additional iron and carbon both from the gas washer wastes and from the pickle liquor, and help solve the problem of pickle liquor disposal. Increased sludge volume and difficulty in reducing moisture contents of the recovered sludge may

result from coagulation.

(c) Segregation and Re-Use - Segregation of blast furnace gas wash water and its recirculation in a separate system is reported as being practiced at one plant. Treatment of the water consists of plain sedimentation with intermittent treatment, after several passes, by chemical flocculation. Some of the water is withdrawn for cooling slag by direct sprinkling. Such a system would eliminate the release of water to waste and reduce water supply demand. In addition, loss of materials is eliminated (9). If maintenance of sufficient low temperature becomes a problem, discharge of the coagulated and settled water would not be expected to be objectionable. Likewise, excess water due to increases in volume from condensation of vapor in the gases might be so treated before discharge.

One of the washers illustrated in Figure 3 employs recirculation. A small settling unit removes readily settleable material from the wash water at the washer and the supernatant is recirculated to the sprays in the washer. Fresh water use in this washer is 20 gallons per 1000 cubic feet of gas; about 40 gallons are recirculated.

Elimination

(a) Dry Filtration - Dry cleaning of blast furnace gases in all stages eliminates wash water use and is therefore the most effective remedial measure. Dry cleaning is accomplished by following the usual dry dust equipment with apparatus for filtering the gases through fine meshed fabric bags. Efficiency of the bag as a filter is increased as a dust mat forms with service. Dust is removed by such filters to concentrations similar to those obtained by electrical precipitator operation. The dust is removed by taking units of the filter out of operation, shaking, and counter-blowing them. Up until a recent development the bags were of cotton which

necessitated lowering of the gas temperature to prevent charring of the bags. The gas also had to be maintained at temperatures above its dew point. In spite of these complications, thirteen foreign plants were reported using the system (2). A recent development, tested on pilot plant scale, employs filters made of asbestos and glass fiber and a new design for mounting the bags (4). This development eliminates the necessity for cooling the gas and minimizes wear and tear on bags. Altogether the advantages of the new filter development as compared to gas washing installations are overwhelming (9). Among these advantages are: (1) elimination of water pollution, (2) less cost of installation and operation, (3) less space required, (4) cleaner gas, (5) higher flame temperatures and improved heat recovery, and (6) less pressure loss. Recovering the dust in a dry state makes possible injection of the dust into the blast furnace at the mantle by means of compressed blast furnace gas. This practice has been followed successfully in Europe since 1926. The necessity of settling the dust from wash water, and the filtering and sintering operations are eliminated. The cost of flue dust disposal is reported to be considerably reduced.

(b) Reduction Measures. Short of complete dry cleaning of the gas, it is obvious that the greater portion of the dust which is removed in the dry state the less will remain for wet washing operations. Optimum design of momentum and cyclone dustcatchers is discussed by Jennings (2). Contrary to what might be expected the different phases of dust cleaning do not each in turn remove particles down to a certain size. A substantial amount of even the finest particles is removed in the dustcatcher and primary wash phases (2).

Sintering of ores lessens dust production by, in effect, removing the

dust before it is charged to the furnace. The fine ore particles are combined by incipient fusion to larger particles. Liberal use of water on stock charged to the furnace is stated to reduce flue dust production.

Electric precipitators may be operated dry thus eliminating the waste irrigation and spray water. It is stated that the dry type is not as efficient as the wet type.

For most blast furnace gas uses, cleaning of the gas beyond the dry dust-catcher phase is in many cases unnecessary or even undesirable according to Gilg (10). It follows that wet washing of most of the gases could be omitted. Since it is likely that the dust content of the gases will, to a certain extent, be carried to the atmosphere through the stacks of equipment using the gases, reservations in advocating the use of uncleaned gas as a remedial measure for water pollution must be made.

As explained in the section on process, reduced velocities of gases in the blast furnace are achieved under certain conditions of top pressure operation. Top pressure experience is rather limited (11). Top pressure operation at reduced velocities has decreased considerably the quantities of flue dust as shown in the following table (12) (13).

Plant No.	Top Pressure psi	Air Blast cfm	Flue Dust Per Ton of Product, Pounds
1	2	78000	270
	3.1	72200	213
	9.7	73400	145
	9.7	83000	170
2	Normal	67500	280
	10	80000	240
3	Normal	85000	278-305
	10	95600	125

This accomplishment in reduction of flue dust is also apparent from the data on volume and character of wastes reported in a previous section. Suspended solids in gas wash water wastes of a furnace operating at about 16 psi top pressure averaged 46 pounds per ton of pig iron produced, while those of a furnace at the same plant operating under normal pressure amounted to 63 pounds.

In top pressure operation, increased pressure advantages are not limited to the blast furnace itself, although of the 6 furnaces in the country reported utilizing high pressure as of 1950, most limited pressure to the furnace only. Operation of gas cleaning equipment under pressure reduces gas velocities in the equipment. Reduced velocities increase the efficiency of the gas cleaning units.

The use of oxygen enriched air for the furnace blast has received attention in recent years. Oxygen has been reported used in blast furnaces on plant scale by two companies. If operation practice, when using oxygen, is such that gas velocities are reduced in the blast furnace, the use of oxygen would be expected to reduce dust production.

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